Conversion of Starch into Sugars

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Carbohydrates and Fermentable Sugars

- Carbohydrates, or "hydrates of carbon," are an important group of naturally occurring organic compounds.
- Commonly these are formed by green plants through photosynthesis
- Carbohydrates are any of the various compounds comprised of carbon, hydrogen and oxygen, general formula $C_x(H_20)_y$
- Carbohydrates are used to store energy until required by the organism
  - Sugars, starches, cellulose, glycogen and related substances
- Saccharides, the simplest form of carbohydrates, consist of single sugar units with five or six carbon atoms in ring form
  - They are commonly called "sugars" or "sweeteners"

Carbohydrates and Fermentable Sugars

- Starch and cellulosic compounds are polymeric molecules
  - Made up of basic unit called monomers
  - These monomers are joined together by a chemical bond called a glycosidic link
- Carbohydrates can be divided into four basic classes
  - Monosaccharides
  - Diasaccharides
  - Oligosaccharides
  - Polysaccharides
    - Each of these comprises of successively more of the same basic unit or units

Carbohydrates and Fermentable Sugars

- Monosaccharides
  - Glucose and Fructose
    - Can be fermented to ethanol by yeast, only under anaerobic conditions

Carbohydrates and Fermentable Sugars

- Diasaccharides
  - Sucrose and Maltose
  - Sucrose is fructose and glucose molecule linked together
  - Sucrose is obtained from sugar cane and sugar beets
  - Commonly known as table sugar
  - Maltose comprises of two molecules of glucose linked together
  - Both maltose and sucrose are fermentable to ethanol by yeast

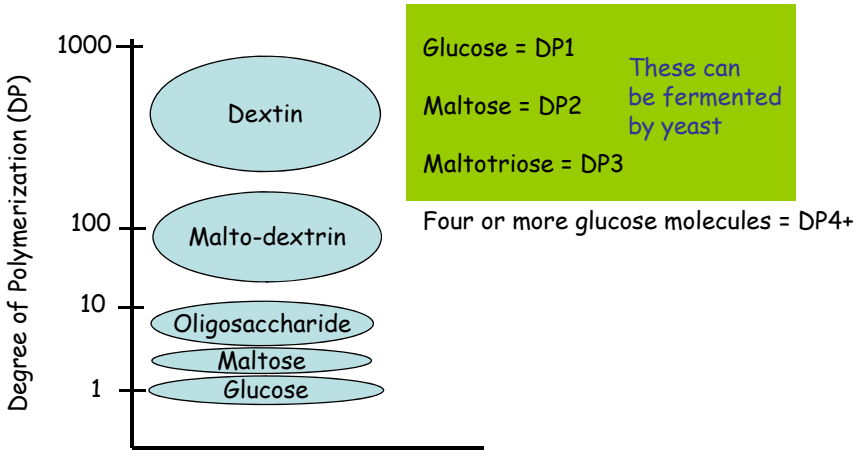
Carbohydrates and Fermentable Sugars

- Oligosaccharides
  - Are saccharides with more than three but less than eight units
  - Oligosaccharides can not be fermented by yeast to produce ethanol

Carbohydrates and Fermentable Sugars

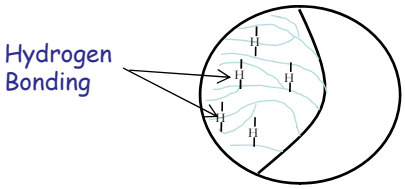
- Polysaccharides
  - Polymeric carbohydrates of many thousand of monomeric sugar units linked together through glycosidic linkages
  - Starch, glycogen or cellulose
  - Neither starch or cellulose can be directly fermented by yeast to produce ethanol
  - Must be hydrolyzed to fermentable sugars

Degree of Polymerization (DP)

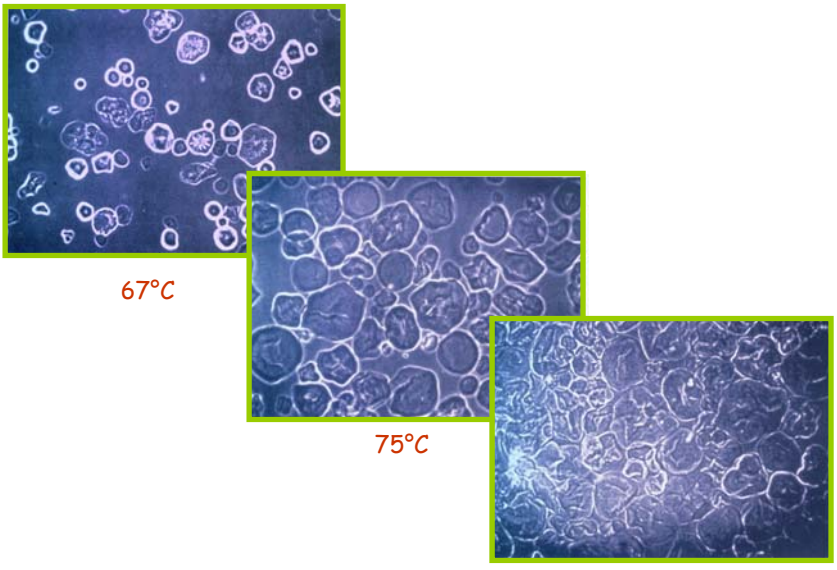


Starch Structure

- Crystallinity
  - Packing of amylose and amylopectin within starch granule is not random but is very organized
  - Prevents enzymes to breakdown starch granule
  - Can be disrupted by gelatinization of starch

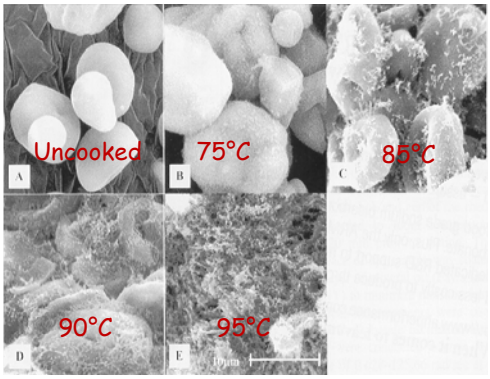


Gelatinization of Starch



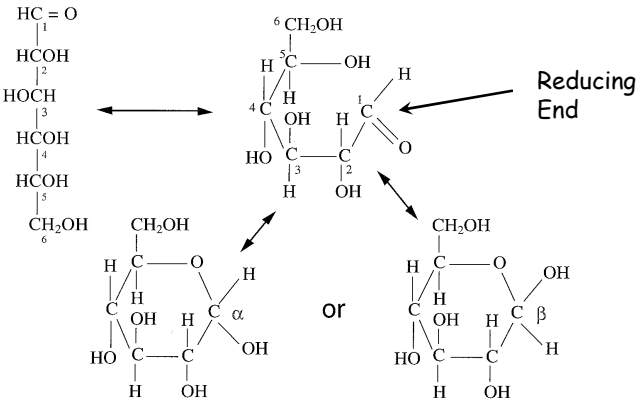
Solubilization of Starch Granules

- Even at 95°C not all of the starch gets solublized (pasted or gelatinized)
- Needs to be cooked for 5 minutes at 110°C to completely solubilize starch
- Pasting or gelatinization temperature starts at 60°C, but is not complete until > 105°C



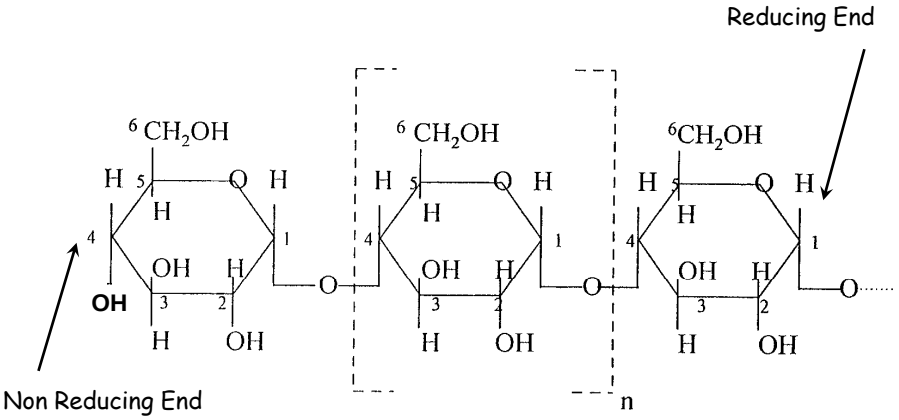
Dextrose Equivalent

- Glucose is a reducing sugar
  - Free aldehyde group on carbon-1



Dextrose Equivalent

- In starch molecule



Dextrose Equivalent

- With each hydrolytic cleavage of an alpha 1,4 or alpha 1,6 bonds, one reducing group on a glucose molecule is freed
- Dextrose equivalent is measure of the percentages of glucosidic bonds that are hydrolyzed
- DE is determined by measuring the amount of reducing sugars in a sample relative to the amount of dextrose
- As starch is hydrolyzed, more and more dextrose is produced, and the amount of reducing sugars and DE increase

Dextrose Equivalent

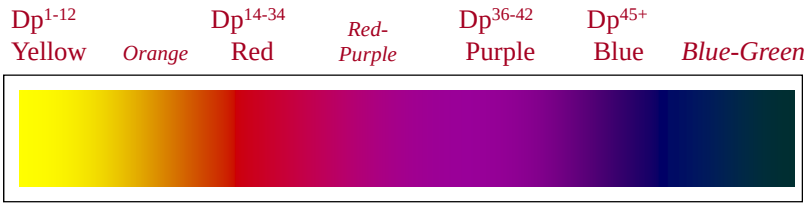
- The standard DE method involves treating a reducing sugar solution with a standard copper reagent and measuring the amount of cupric ion (Cu^{+2}) remaining after reaction; the more Cu^{+2} that is reduced to Cu^{+}, the higher the DE
- DE of dextrose is 100, representing 100% hydrolysis
- DE of malto-dextrins ranges from 5-20
- Dextrose syrups, which have DE>95 are often referred to as liquid dextrose

Blue Iodine Color

- When Iodine complexes with starch, it forms a color complex which is different for amylose and amylopectin
- The goal of the system and enzyme are to solubilize and lower all the starch in the grain—indicated by an amber to yellow iodine test color.

Iodine Color - Facts

- Different chain lengths = different colors
- All color changes occur between Dp^{12} & Dp^{45}
- Six glucose units are required per iodine
- Retrogradation occurs with Dp^{150} - Dp^{200} oligosaccharides

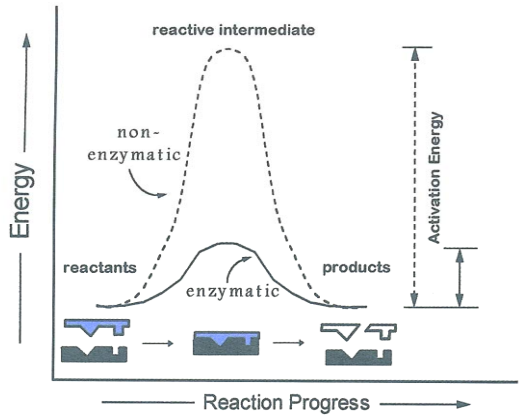


Enzymes

- Enzymes are a type of protein present in, and essential to, all living things
- Enzymes act as biological catalysts
  - They increase the rate of chemical reactions without undergoing any permanent change themselves
- Enzyme are not consumed in the reaction
  - Can continue to catalyze a reaction as long as the proper reactants are available
- The surface of each enzyme contains various chemical groups that can react with small molecules
  - High degree of specificity

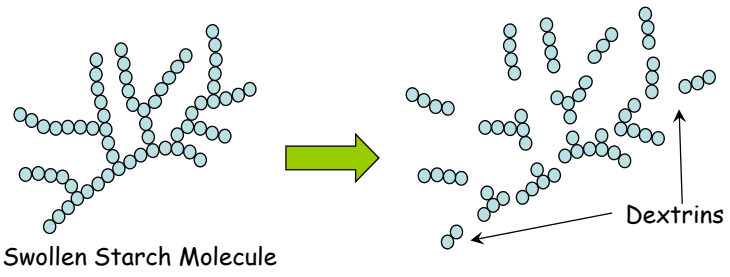
Enzymes

- Comparison of enzymatic and nonenzymatic reaction kinetics

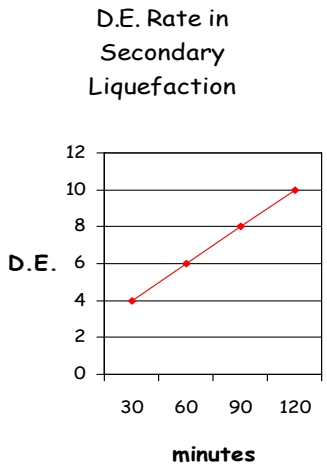


Liquefaction

- Liquefaction is the process of turning starches, into smaller molecules called dextrins
  - Alpha amylase (AA) enzyme is need for Liquefaction
  - Granular structure of starch needs to be broken before AA can bring about hydrolysis of starch to dextrins
  - AA breaks randomly breaks alpha 1,4 glucosidic linkages but not alpha 1,6 linkages



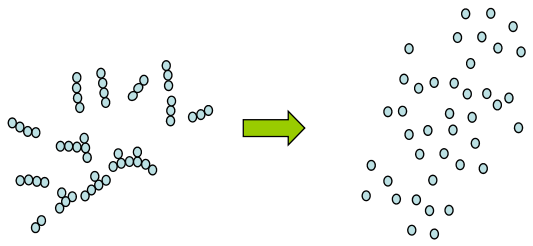
Typical Alpha Amylase D.E. Development in Liquefaction



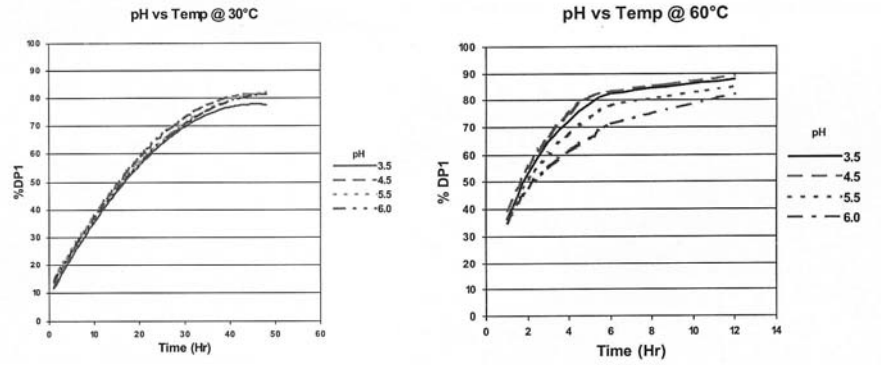
- The rate of D.E. is dependent on conditions mentioned above
- By increasing the dose 50%, the rate increases by 50%
- Mash iodine color should be purple to amber to be "starch negative—blue color means raw starch is still present.

Saccharification

- New dry grind ethanol plants do Simultaneous Saccharification and Fermentation (SSF)
- Some plants still have separate saccharification process



Saccharification versus SSF



Different Enzyme Actions